

Comparative evaluation of effectiveness indexes of column packings in benzol absorbers

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Abstract. Coke-oven gas is produced during coking of charge coal in a coking chamber and it constitutes a mix of different substances. A composition of different components in the gas depends on a composition of the coal charge and conditions of the coking. At a recovery plant, aromatic hydrocarbons are retrieved from the coking gas by absorption oil in packed absorbers. Mass-transfer apparatus demand the equability of the phase distribution. Hydrodynamic conditions, appearing inside contacting apparatus, determinate the effectiveness of the mass-transfer, which means that unbiased evaluation of any given mass-transfer apparatus can be made while simultaneous considering its hydrodynamic and mass-transfer indicators. The different types of column packing have been investigated in this study. The calculations of benzol absorbers have been performed basing on the initial data using the standard methodologies for the recovery plant of JSC EVRAZ NTMK coke and by-product enterprise. For comparison of the results obtained, the complex indexes of effectiveness, that simultaneously take into account the mass-transfer rate, the device capacity, the features of packings and energy cost, have been used.

1. Introduction

The most part of by-product coke plants is characterized by excessive losses of raw benzol with a reverse coke gas, which explains the practical interest in studying the technology of raw benzol recovery from the coke gas and in studying technical means ensuring effectiveness of an absorption process. After the final gas coolers, the coke gas contains 32–35 g/m³ of aromatic hydrocarbons. The basis of the latter is benzol itself and its homologues, that are toluene, xylenes and trimethylbenzenes [1].

The effectiveness of the aromatic hydrocarbons recovery from the coke gas depends on: compositions of the gas and absorption oil, temperature and pressure, hydrodynamic conditions of phase motion in the apparatus. The composition of the coke gas depends on the coal charge composition and conditions of coking. The composition of the absorption oil is controlled by the central laboratory. The absorbing capacity of oils decreases with increase of the temperature and growth of the molecular weight of an absorbent and its viscosity. Furthermore, the absorbing capacity of the oil significantly decreases in the case of water influx [2].

It is known that if the temperature reduces, the solubility of gases in the absorbent increases. At the temperature of 10°C, the viscosity of the oil increases sharply, and precipitation is also possible, which contaminates the packing and increases the hydraulic resistance of the absorber. For that reason, the process is conducted at the optimum temperature of the gas of 25°C. To avoid the condensation of



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water vapor from the coke gas and water influx of the wash oil, the temperature of the latter is kept by 2–3 degrees above the gas temperature [3].

The hydrodynamic conditions of the phase motion depend on selection of the contact devices in the absorber and they considerably determine a surface of inter phase contact, an operating mode of apparatus and its hydraulic resistance. Thus, the intensity of the mass-transfer at the time of absorption depends on selection of a packing. The data on influence of a packing surface on an extent of benzol hydrocarbons absorption is given in [4].

The upcoming reconstruction of the recovery plant of JSC EVRAZ NTMK coke and by-product enterprise, aimed at consolidation of two departments, makes this study relevant, since during the reconstruction it is possible to provide an option of substitution of an old packing in the benzol absorbers.

2. Main part

Due to the petrochemical industry development, a large number of new types of packings of regular and irregular type from various manufacturers have recently come to the market, including: EPC 'Ingehim'; 'Sulzer Chemtech'; RPC 'Kedr-89'. Detailed description of the packings, recommendations on their work conditions, calculation and empirical data on their operation are introduced in separate scientific articles [5–8] and monographs [9–11].

The following factors are essential in terms of the packing selection in the by-product coke industry: low hydraulic resistance, ability to operate steadily under strongly varying gas loads, ability to remove deposited sludge from the packing surface quickly and on the cheap, high corrosion resistance and mechanical strength [12].

In order to calculate the parameters of the absorbers, the following values [12], that are compliant with the data [1] and exceed the average performance indicators of recovery plant No. 3 in the second half of 2018, have been taken as the initial data (Table 1).

Table 1. Initial data for calculation.

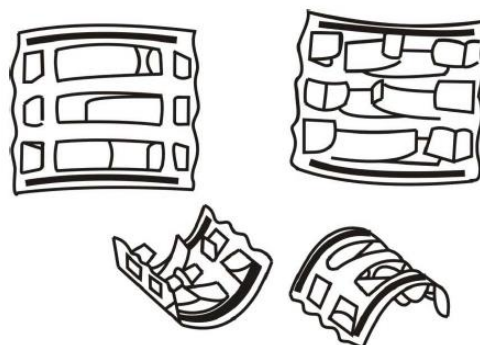
Gas production rate, m ³ /h	100.000
Content of BH in the gas at the inlet to absorber, kg/m ³	32.5 · 10 ⁻³
Content of BH in the gas at the outlet from absorber, kg/m ³	3 · 10 ⁻³
Content of BH in the washing oil at the inlet to absorber, %	0.25
Temperature inside the apparatus, °C	30
Gas pressure at the inlet to absorber, Pa	0.12 · 10 ⁶
Density of the coke gas, kg/m ³	0.453
Density of the wash oil, kg/m ³	1.010

Currently a Z-shaped packing and a wood grid packing are used in the absorbers at JSC EVRAZ NTMK coke and by-product plant. This study investigates more up-to-date types of regular and irregular packings offered by the manufacturers 'Sulzer Chemtech' [13], LLC EPC 'Ingehim' [14] and others considered in details in [9].

In the industry, irregular packings with a lower cost are still used to a much greater extent, especially at large-tonnage plants with large-diameter mass-transfer apparatus for realization of absorption-desorption processes. Irregular packing Ingehim-2000 and Leva have been chosen basing on the results of evaluation [9], where it is shown that they have the highest relative effectiveness in regard to the Raschig ring packing.

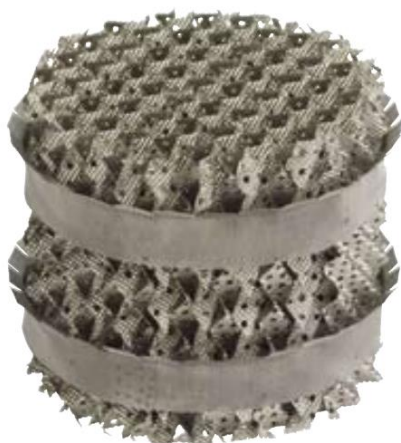
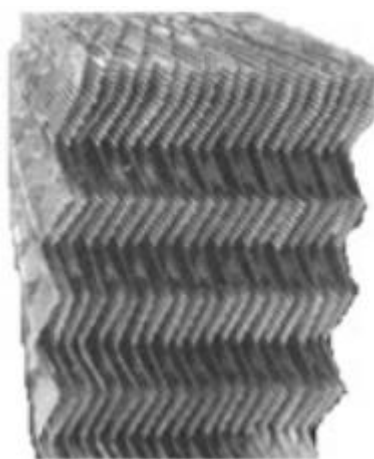
Packing Ingehim-2000 (Figure 1) is made of a sheet or strap of corrosion-resistant or carbon steel with the thickness from 0.3 to 2 mm. This packing is applicable to the polluted and corrosive environments. A surface of the sheet is exposed to special metalwork enhancing liquid spreading on the packing.

Packing Leva (Figure 2) is a metal saddle packing in the shape of semi-ring with rectangular perforation and petals bent inwards. This packing forms packed layers with a quite loose structure, due to which it has high capacity and low hydraulic resistance.

**Figure 1.** Element of packing Ingehim-2000.**Figure 2.** Elements of packing Leva.

Regular packings have a number of advantages compared to irregular ones: absence of liquid hold-up spots at points of contact between elements of an irregular packing, presence of theoretic possibility of 100% wetting of the packing surface with a liquid. Presence of regular-shaped channels contributes to lower hydraulic resistance per height unit of a packed layer and greater capacity. An enlarged surface of phase contact leads to an increase in the effectiveness [9].

Regular block packings have recently gained common use due to significant simplification of works on set up of the packings into the absorber. In terms of its properties, a block packing is as good as other types of regular packings [15]. The disadvantages of the regular block packings include sensitivity to equality of distribution of irrigation over the entire area of the packing and high cost.

**Figure 3.** Packing Mellapak.**Figure 4.** Packing Vakupak.**Figure 5.** Packing IRG.

Packing Mellapak produced by ‘Sulzer Chemtech’ (Figure 3) consists of inter-bedded layers of a perforated metal sheet of a light thickness (0.15–0.25 mm). Corrugation in adjoining layers of the packing are turned in opposite directions.

Indigenous packing Vakupak (a joint development project of VNIINEFTEMASH with ‘Apparate-und Anlagenbau Germania’ company [16,17]) (Figure 4) constitutes itself a package of vertical plates fabricated by a horizontal corrugation method. The corrugation has bent and downward directed protrusions with holes that provide an assigned distance between adjoining plates during production of a packing. The liquid flows down the corrugation in the form of a film, and the gas moves from the

bottom upwards in gaps between corrugated sheets. The protrusions of the corrugation provide intensive internal mixing and breakdown of liquid and vapor flows [13].

Packing IRG (Ingechim Regular Gofr; EPC ‘Ingehim’) (Figure 5) constitutes itself a package of vertically installed metal corrugated plates. The corrugation of the plates is located at an angle to the horizon. The package is arranged in a way that a corrugation of adjoining plates is located crosswise.

The parameters of the packings necessary for calculation of the absorbers are presented in Table 2.

Table 2. Characteristics of packings.

Parameter	Regular packings			Irregular packings	
	Vakupak [17]	Mellapak [18]	IRG [9]	Ingehim-2000 [14]	Leva [9,19]
Specific surface area of a packing a , m ² / m ³	115.0	92.0	162.0	62.2	118.0
Void volume ε , m ³ / m ³	0.980	0.954	0.980	0.967	0.980
Equivalent diameter of a packing d_e , m	0.035	0.042	0.024	0.056	0.033

The calculations have been performed according to the standard methodology suggested in [12]. The results show (Table 3) that the main regularities are fulfilled: the higher the mass-transfer coefficient value, the smaller the required mass-transfer surface. The total height of a packing is calculated taking into account data on the specific surface (Table 2).

Table 3. Parameters of absorbers with different packing types.

Parameter	Regular packings			Irregular packings	
	Vakupak	Mellapak	IRG	Ingehim-2000	Leva
Mass-transfer coefficient $K_s \cdot 10^{-4}$, kg/(m ² ·s)	0.79	0.35	0.54	1.14	0.56
Mass-transfer surface $F \cdot 10^5$, m ²	12.85	28.16	18.24	8.55	17.39
Diameter of an absorber d , m	3.2	3.8	3.6	3.2	4
Height of a packing H , m	129	99	107	143	117
Hydraulic resistance of an absorber ΔP , Pa	8,224	7,686	6,029	4,784	3,572
Number of absorbers n , pcs	4	3	3	4	4

Thus, the mass-transfer coefficient of an absorber with packing Ingehim-2000 has a maximum value, however, the total height of the packing turns out to be larger than in other cases due to the small specific surface. The optimum total height of the packing is ensured by the contact devices like Mellapak and IRG, which allows conducting retrieval of the aromatic hydrocarbons in three sequentially installed absorbers.

3. Results and discussion

To evaluate the operation effectiveness of different column packings of absorption apparatus, the authors [4, 20] suggest to use value I as a summarizing indicator of intensity. It comprises the capacity and intensity characteristics of the inter-phase exchange:

$$I = \frac{w}{h}$$

where w is the maximum allowed gas velocity in the cross-section of the apparatus, m/s; h is the height of mass transfer unit, m.

To compare the energy losses for gas passing through the absorber [4,20], it is allowed to use index $N/\Delta P$ (kPa⁻¹), where N means a number of mass transfer units.

Table 4. Indexes of operation effectiveness of column packings.

Parameter	Regular packings			Irregular packings	
	Vakupak	Mellapak	IRG	Ingehim-2000	Leva
Limiting gas velocity ω_{lim} , m/s	8.4	5.7	7.1	8.1	5.3
Height of mass transfer unit h , m	2.08	2.29	2.34	2.22	2.91
Indexes of intensity I	4.05	2.49	3.03	3.65	1.83
$N/\Delta P$	0.43	0.46	0.58	0.73	0.98

When comparing different options for equipping the absorber, a technical solution capable of providing the maximum limiting velocity and $N/\Delta P$ at a minimum height of transfer unit is admitted optimal. Under otherwise equal conditions, an option with the greatest value I is selected [20].

With regard to the results given in Tables 3 and 4, based on the total of parameters, packing IRG can be recommended to use in the absorbers: the plant will be comprised of three absorbers, likewise Mellapak, but in contrast to it, packing IRG has higher indexes of intensity. Packing Leva has the highest values $N/\Delta P$, which corresponds to the minimum energy cost, but is inferior in all other indicators.

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